UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

USGS-OFR--81-188

DE82 905953

Principal Facts for Gravity Stations of the
Broadwater Geothermal Area, Montana

by

Viki Bankey, Jody Paton, and M. Dean Kleinkopf

Open-File Report 81-188

1981

This report is preliminary and has not
been reviewed for conformity with
U.S. Geological Survey editorial standards.

Use of brand names is for descriptive purposes and does not
constitute endorsement by the U.S. Geological Survey.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

PURCHASE ORDER NO. 03X-46503

RECEIVED

9-3-82

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Contents

	Page
Introduction	1
Data collection	1
Elevation control	1
Data reduction	2
References	3

Illustration

Figure 1 - Index map, Broadwater geothermal area, Montana	4
--	---

Appendices

A. Helena Airport base description	5
B. Broadwater base description	6
C. Principle facts	7
D. Bouguer gravity map of the Broadwater geothermal area, Montana	Large map

Introduction

On August 18-19, 1979, 67 gravity stations were established at the Broadwater Hot Springs area 5 km west of Helena, Montana (Fig. 1). The gravity data were obtained as part of the U.S. Geological Survey's program to evaluate geothermal resource areas. These data complement a 1978 gravity survey by M. Senterfit (1979) and a telluric profile done by K. Christopherson (1979). This report presents the principle facts for the 1979 gravity data.

Data Collection

Gravity observations were made with the LaCoste-Romberg gravity meter, G-235. The International Gravity Standardization Net (IGSN), 1971, established by the Defense Mapping Agency Aerospace Center (1974) was used as the datum for the U.S. Geological Survey gravity base at Helena, Montana. A secondary base, which was tied to the Helena base, was established in the study area. Base descriptions are given in Appendices A and B detail at the end of the present report. Gravity loops were started and closed daily by observations at these bases.

Elevation Control

The Broadwater geothermal area is located in the area covered by the Helena quadrangle, scale 1/62,500. Station elevations were surveyed using a Hewlett-Packard Total Station distance meter. The elevations were tied to a known elevation of 233.62 m at the Broadwater Bridge Base (BR-2), determined by R. Leonard (oral communication, 1978). The elevation differences obtained with this instrument in this terrain were estimated to

have a precision of 0.15 m for distances less than 2 km. This precision translates to uncertainties in Bouguer values of 0.03 (milligals). Horizontal distance at this range is also accurate to within 0.15 m.

Data Reduction

Computer programs on the USGS Honeywell Multics computer system were used to obtain principle facts and terrain corrected gravity values. A program by D. A. Dansereau (USGS, unpublished) was used to calculate earth-tide and linear meter-drift corrected observed gravity values. The theoretical gravity value was calculated using the 1967 formula of the Geodetic Reference System (International Association of Geodesy, 1967). Another unpublished program by R. H. Godson computed terrain corrections for the area from each station out to 166.7 km, using the method of Plouff (1977). The program uses mean elevation data on a 15-second grid for corrections from 0 to 5 km; 1-minute terrain data for corrections from 5 to 21 km; and 3-minute terrain data for corrections from 21 to 166.7 km. An assumed density of 2.67 g/cm³ is used for terrain corrections. This program also calculates earth-curvature corrections and complete (terrain-corrected) Bouguer anomaly values. Corrections for terrain ranged from 0.89 to 3.18 mgal. Two complete Bouguer anomaly values per station were calculated assuming average rock densities of 2.67 g/cm³ and 2.45 g/cm³. The corrections and anomaly values are listed in Appendix C. A hand contoured Bouguer gravity map is included in Appendix D.

References

- Christopherson, K. 1979, Telluric profile and location map for the Broadwater Hot Springs area, Montana: U.S. Geological Survey Open-File Report, 79-1670.
- Defense Mapping Agency Aerospace Center, 1974, World relative gravity reference network, North America, Part 2: DMAAC Reference Publication 25, with supplement updating gravity values to the International Gravity Standardization Net 1971, 1635 p.
- International Association of Geodesy, 1967, Geodetic reference system, 1967: International Association of Geodesy Special Publication 3, 74 p.
- Plouff, D., 1977, Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid: U.S. Geological Survey Open-File Report, 77-535.
- Senterfit, R. M., 1979, Principal facts for gravity stations of the Broadwater, Montana geothermal area: U.S. Geological Survey Open-File Report, 79-1624.

Fig. 1 - Index Map
Broadwater Hot Springs, Montana

Appendix A

U.S. GEOLOGICAL SURVEY
GRAVITY BASE STATION

STATE/COUNTRY		STATION DESIGNATION		OBSERVED GRAVITY
Montana		Helena Airport		980363.26 mgals
NEAREST TOWN		LONGITUDE		LATITUDE
Helena		111° 59.50'		46° 36.50'
ELEVATION		TOPOGRAPHIC MAP(S)		
1180.3 m (3872')		White Sulphur Springs 1/250,000		
DATE	OBSERVER	METER	REFERENCE STATION	REFERENCE VALUE
7/2/77	Kleinkopf	Worden E-134	Helena airport DOD	980363.50 mgals

DESCRIPTION/SKETCH

Base is on concrete walk at southeast corner of the airport terminal building, to west side of outside stairway - "employee entrance". Note the DOD location is on north side of the terminal in the security area.

Appendix B

U.S. GEOLOGICAL SURVEY
GRAVITY BASE STATION

STATE/COUNTRY Montana		STATION DESIGNATION Broadwater		OBSERVED GRAVITY 980347.42 mgal.
NEAREST TOWN Helena		LONGITUDE 112° 06.74'		LATITUDE 46° 35.74'
ELEVATION 4047.3 feet (1234 m)		TOPOGRAPHIC MAP(S) Helena 15', Butte 2°		
DATE	OBSERVER	METER	REFERENCE STATION	REFERENCE VALUE
8/19/79	Bankey	G-235	Helena Airport	980363.26 mgal.

DESCRIPTION/SKETCH

Base is approximately one mile past turnoff to State Nursery, west of Helena on Highway U.S. 10N. Base is on northwest corner of bridge at turnoff to hot springs area which is being made into a resort.

Appendix C: Principal Facts of Gravity Data

Explanation of headings

identification

proj	Project name.
sta-id	Gravity station identification number.

location

latitude	North latitude, in degrees, minutes, and hundredths of minutes.
longitude	West longitude, in degrees, minutes, and hundredths of minutes.
elev f	Station elevation, in feet.
st	State in which survey area is located.
observed gravity	Observed gravity, in milligals.
theoretical gravity	Theoretical gravity.

corrections

terrain	Terrain correction to 166.7 km in milligals.
Bouguer	Elevation correction, in milligals.
curv	Earth curvature correction, in milligals.
special	Not used.

anomalies

free air	Free-air anomaly, in milligals.
complete-Bouguer	Complete Bouguer anomaly, in milligals for designated densities.
spec fields	Not used.

BOUGUER GRAVITY DATA

broadwater gravity file
 bankey and patton 1979
 Meter ID: g-235 Date: 11/27/79

STATION		L U C A T I O N S				G R A V I T Y		C O R R E C T I O N S				A N O M A L I E S			
IDENTIFICATION		LATITUDE	LONGITUDE	ELE	ST	OBSERVED	THEORETICAL	TERRAIN	BOUGUER	CURV	SPECIAL	FREE	COMPLETE	-BOUGUER	SPEC
proj	sta-id	deg	min	deg	min	(in ft)						AIR	d1=2.67	d2=2.45	FIELDS
north :	br1	46	36.25	-112	7.26	4596.5 MT	980317.65	980764.18	2.46	-156.77	-1.36	0.00	-14.41	-170.08	-157.26
north :	br2	46	35.74	-112	6.74	4047.3 MT	980347.42	980763.41	2.51	-138.04	-1.27	0.00	-35.48	-172.28	-161.01
north :	br4	46	36.14	-112	6.63	4218.6 MT	980340.49	980764.02	1.19	-143.88	-1.30	0.00	-26.92	-170.91	-159.04
north :	br5	46	36.14	-112	6.50	4170.6 MT	980343.24	980764.02	1.39	-142.25	-1.29	0.00	-28.68	-170.83	-159.11
north :	br6	46	36.15	-112	6.81	4272.6 MT	980337.60	980764.03	1.15	-145.73	-1.31	0.00	-24.75	-170.63	-158.61
north :	br7	46	36.15	-112	7.07	4328.0 MT	980334.63	980764.03	1.03	-147.62	-1.32	0.00	-22.51	-170.41	-158.23
north :	br8	46	36.15	-112	7.20	4395.6 MT	980330.45	980764.03	0.91	-149.92	-1.33	0.00	-20.34	-170.67	-158.29
north :	br9	46	36.04	-112	7.25	4401.5 MT	980329.83	980763.87	0.98	-150.12	-1.33	0.00	-20.24	-170.71	-158.31
north :	br10	46	35.96	-112	7.19	4397.0 MT	980329.25	980763.75	1.24	-149.97	-1.33	0.00	-21.12	-171.18	-158.81
north :	br11	46	35.98	-112	7.08	4296.6 MT	980335.62	980763.77	1.18	-146.54	-1.31	0.00	-24.22	-170.90	-158.81
north :	br12	46	36.01	-112	6.95	4229.1 MT	980339.43	980763.82	1.45	-144.24	-1.30	0.00	-26.80	-170.89	-159.02
north :	br13	46	36.06	-112	7.00	4272.1 MT	980337.35	980763.90	1.33	-145.71	-1.31	0.00	-24.91	-170.59	-158.59
north :	br14	46	36.31	-112	6.98	4558.7 MT	980320.16	980764.27	2.77	-155.48	-1.35	0.00	-15.54	-169.60	-156.91
north :	br15	46	36.15	-112	7.47	4512.4 MT	980324.78	980764.03	1.19	-153.91	-1.35	0.00	-15.03	-169.09	-156.40
north :	br16	46	36.27	-112	7.50	4427.0 MT	980330.38	980764.21	0.90	-150.99	-1.33	0.00	-17.64	-169.06	-156.58
north :	br17	46	36.35	-112	7.47	4380.2 MT	980333.65	980764.34	0.89	-149.40	-1.32	0.00	-18.89	-168.72	-156.38
north :	br18	46	36.15	-112	7.32	4520.8 MT	980323.07	980764.03	1.52	-154.19	-1.35	0.00	-15.95	-169.97	-157.26
north :	br19	46	36.22	-112	6.92	4383.8 MT	980331.45	980764.14	1.04	-149.52	-1.33	0.00	-20.55	-170.36	-158.01
north :	br20	46	35.97	-112	6.61	4139.2 MT	980344.04	980763.76	1.54	-141.18	-1.28	0.00	-30.58	-171.50	-159.89
north :	br21	46	36.01	-112	6.72	4176.8 MT	980342.24	980763.82	1.44	-142.46	-1.29	0.00	-28.90	-171.21	-159.48
north :	br22	46	35.99	-112	6.82	4170.4 MT	980342.55	980763.79	1.57	-142.24	-1.29	0.00	-29.17	-171.13	-159.43
north :	br23	46	35.94	-112	6.91	4179.5 MT	980341.78	980763.72	1.53	-142.55	-1.29	0.00	-29.00	-171.31	-159.59
north :	br24	46	35.04	-112	6.99	4056.6 MT	980346.96	980763.27	3.18	-138.36	-1.27	0.00	-34.92	-171.37	-160.13
north :	br25	46	35.80	-112	6.92	4128.6 MT	980343.87	980763.51	1.94	-140.81	-1.28	0.00	-31.49	-171.65	-160.10
north :	br26	46	35.83	-112	6.87	4116.4 MT	980344.64	980763.55	2.00	-140.40	-1.28	0.00	-31.91	-171.59	-160.08
north :	br27	46	35.77	-112	6.81	4059.8 MT	980347.38	980763.46	2.48	-138.47	-1.27	0.00	-34.39	-171.65	-160.34
north :	br28	46	35.83	-112	6.76	4067.3 MT	980347.27	980763.55	2.16	-138.72	-1.27	0.00	-33.89	-171.73	-160.37
north :	br29	46	35.79	-112	6.70	4034.2 MT	980348.64	980763.49	2.45	-137.59	-1.27	0.00	-35.53	-171.94	-160.70
north :	br30	46	35.83	-112	6.65	4039.2 MT	980348.73	980763.55	2.25	-137.77	-1.27	0.00	-35.07	-171.85	-160.58
north :	br31	46	35.82	-112	6.61	4031.6 mt	980348.97	980763.54	2.30	-137.51	-1.27	0.00	-35.53	-172.01	-160.76
north :	br32	46	35.82	-112	6.58	4030.9 mt	980349.07	980763.54	2.27	-137.48	-1.27	0.00	-35.50	-171.98	-160.73
north :	br33	46	35.82	-112	6.55	4031.0 mt	980349.04	980763.54	2.21	-137.49	-1.27	0.00	-35.52	-172.06	-160.81
north :	br34	46	35.81	-112	6.60	4033.6 mt	980348.80	980763.52	2.29	-137.57	-1.27	0.00	-35.50	-172.05	-160.80
north :	br35	46	35.78	-112	6.63	4041.6 mt	980348.17	980763.48	2.35	-137.85	-1.27	0.00	-35.33	-172.10	-160.83
north :	br36	46	35.79	-112	6.53	4039.3 mt	980348.34	980763.49	2.21	-137.77	-1.27	0.00	-35.39	-172.22	-160.94
north :	br37	46	35.88	-112	6.69	4093.6 mt	980346.23	980763.63	1.79	-139.62	-1.26	0.00	-32.53	-171.64	-160.18
north :	br38	46	35.89	-112	6.60	4107.4 mt	980345.41	980763.64	1.63	-140.09	-1.26	0.00	-32.07	-171.81	-160.30
north :	br39	46	35.67	-112	6.66	4180.5 mt	980339.21	980763.31	1.75	-142.59	-1.29	0.00	-31.07	-173.20	-161.49
north :	br40	46	35.69	-112	6.58	4206.4 mt	980338.02	980763.34	1.61	-143.47	-1.30	0.00	-29.85	-173.01	-161.21
north :	br41	46	35.79	-112	6.49	4205.5 mt	980338.54	980763.49	1.71	-143.44	-1.30	0.00	-29.57	-172.60	-160.81

BOUGUER GRAVITY DATA

broadwater gravity file
 bankey and patton 1979
 Meter ID: g-235 Date: 11/27/79

STATION		L O C A T I O N S				G R A V I T Y		C O R R E C T I O N S				A N O M A L I E S					
IDENTIFICATION		LATITUDE		LONGITUDE		E L E S T		OBSERVED THEORETICAL		TERRAIN BOUGUER CURV		SPECIAL		FREE COMPLETE-BOUGUER		SPEC	
proj	sta-id	deg	min	deg	min	(in ft)								AIR	d1=2.67	d2=2.45	FIELDS
north :	br42	46	35.72	-112	6.58	4114.1	mt	980343.65	980763.38	2.07	-140.32	-1.28	0.00	-32.95	-172.48	-160.98	
north :	br43	46	35.70	-112	6.66	4101.2	mt	980343.92	980763.35	2.32	-139.88	-1.28	0.00	-33.86	-172.70	-161.26	
north :	br44	46	35.91	-112	6.51	4103.8	mt	980345.47	980763.67	1.64	-139.97	-1.28	0.00	-32.38	-171.99	-160.49	
north :	br45	46	35.87	-112	6.55	4095.1	mt	980345.98	980763.61	1.68	-139.67	-1.28	0.00	-32.62	-171.89	-160.42	
north :	br46	46	35.94	-112	6.64	4130.8	mt	980344.45	980763.72	1.58	-140.89	-1.28	0.00	-30.91	-171.50	-159.91	
north :	br47	46	36.39	-112	6.44	4427.0	mt	980328.77	980764.39	2.19	-150.99	-1.33	0.00	-19.43	-169.56	-157.19	
north :	br48	46	36.37	-112	6.47	4388.7	mt	980331.11	980764.37	1.63	-149.69	-1.33	0.00	-20.66	-170.04	-157.73	
north :	br49	46	36.36	-112	6.31	4306.6	mt	980336.16	980764.35	1.32	-146.89	-1.31	0.00	-23.31	-170.19	-158.08	
north :	br50	46	36.32	-112	6.47	4268.1	mt	980338.40	980764.29	1.09	-145.57	-1.31	0.00	-24.63	-170.42	-158.41	
north :	br51	46	36.31	-112	6.31	4192.7	mt	980343.01	980764.27	1.19	-143.00	-1.29	0.00	-27.09	-170.20	-158.41	
north :	br52	46	36.24	-112	6.43	4191.2	mt	980342.52	980764.17	1.27	-142.95	-1.29	0.00	-27.61	-170.59	-158.80	
north :	br53	46	36.22	-112	6.27	4109.6	mt	980347.57	980764.14	1.34	-140.17	-1.28	0.00	-30.20	-170.31	-158.77	
north :	br54	46	36.17	-112	6.36	4128.7	mt	980345.96	980764.06	1.31	-140.82	-1.28	0.00	-29.94	-170.73	-159.13	
north :	br55	46	36.14	-112	6.22	4057.1	mt	980350.23	980764.02	1.48	-138.38	-1.27	0.00	-32.35	-170.52	-159.14	
north :	br57	46	36.07	-112	6.41	4114.7	mt	980345.86	980763.91	1.40	-140.34	-1.28	0.00	-31.21	-171.43	-159.88	
north :	br58	46	35.99	-112	6.36	4034.0	mt	980349.86	980763.79	1.76	-137.59	-1.27	0.00	-34.67	-171.77	-160.47	
north :	br59	46	35.94	-112	6.45	4071.7	mt	980347.42	980763.72	1.65	-138.87	-1.27	0.00	-33.49	-171.99	-160.58	
north :	br60	46	35.93	-112	6.30	4012.8	mt	980350.74	980763.70	1.89	-136.86	-1.26	0.00	-35.69	-171.93	-160.70	
north :	br61	46	35.83	-112	6.07	4106.5	mt	980345.61	980763.55	1.79	-140.13	-1.28	0.00	-31.68	-171.30	-159.79	
north :	br62	46	35.77	-112	6.18	4149.0	mt	980342.50	980763.46	1.87	-141.51	-1.29	0.00	-30.89	-171.02	-160.21	
north :	br63	46	35.74	-112	6.34	4150.2	mt	980341.55	980763.41	1.77	-141.55	-1.29	0.00	-31.69	-172.76	-161.13	
north :	br64	46	35.64	-112	6.41	4158.1	mt	980340.82	980763.27	2.00	-141.82	-1.29	0.00	-31.52	-172.63	-161.00	
north :	br65	46	35.90	-112	6.11	4074.3	mt	980347.89	980763.66	1.67	-138.96	-1.27	0.00	-32.72	-171.28	-159.87	
north :	br66	46	35.93	-112	6.16	4034.8	mt	980349.61	980763.70	1.69	-137.62	-1.27	0.00	-34.76	-171.95	-160.64	
north :	br67	46	35.84	-112	6.43	4026.6	mt	980349.06	980763.56	2.07	-137.34	-1.26	0.00	-35.94	-172.47	-161.22

BROADWATER 1979 GRAVITY DATA

PURCHASE ORDER NO. 03X-46503
9-3-82